DINSAR Technical Proposal for Study of Soil Subsidence the Neighborhood of Boa Viagem, Recife - PE, Brazil

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Abstract. The overexploitation of groundwater resources can cause several problems; one is the use of wells for situations that require a higher demand on the availability of the well reservoir leading to exhaustion. Another issue is the lowering of soil compaction with the underlying layers of porous, due to water extraction capacity in excess of recharge. This phenomenon is known as subsidence of the soil. This article shows a general review of remote sensing technique, namely DInSAR - Differential Interferometry Synthetic Aperture Radar applied to studies of land subsidence. From these techniques it is possible to see the lowering of the ground with the overexploitation of aquifers. The DInSAR technique is independent of other techniques for measuring subsidence, such as geometric leveling and gravimetric method, whereas the sensor system Advanced Synthetic Aperture Radar orbiter is not located in the soil-building. Other types of phenomena (seismicity, ground works, among other ones) can generate subsidence of land, may occur in the same season and region and overlap the overexploitation of aquifers.

Keywords: DInSAR technique, Soil Subsidence, Remote Sensing.

1. Introduction

The subsidence of the soil is a rheological phenomenon lowering of the ground surface in response of changes in the groundwater by reducing the level of altimetric ground due to the removal of subsurface support (Cabral

et al., 2006; Paula, 2005, Cabral et al. 2001; Cabral et al. 2002; Cabral et al. 2003; Silva, 2004; Chen et al. 2003; Chang et al., 2005; Gonzalez-Moran et al. 1999).

The subsidence of the soil can be triggered by a cause alone or be linked to other natural phenomena, namely, the seismicity generated by movements of normal faults and transcurrent; earthquakes in subduction zones; induced earthquakes and volcanic eruptions dams (Takeya et al . 1989); accommodation sedimentary structures induced by earthquakes collapsing caves (karst dissolution); extraction of gas and oil; structural collapse generated by engineering works of mine as mine collapsed due to vibrations caused by deflagration of explosives and failures structural protection (U.S. Army Corps of Engineers, 2002), and overexploitation of water from aquifers (Cabral, 2001; Santos, 2005). Underground civil engineering (construction of underground canals, tunnels, subways, urban drainage tanks) designed and built incorrectly or without geotechnical surveys, geophysical, geological and geo-hidrological appropriate, can generate subsidence. According to Scott (1979) the phenomenon of subsidence can be seen as a geographical expression in the area, the time consumed and human activity or natural phenomena isolated inducing subsidence, as shown in Table 1.

AREA (km^2)	**TIME INTERVAL (years)**	**HUMAN ACTIVITY/ NATURAL PHENOMENON**
10^2 a 10^3	10^4	Isostatic adjustments of the crust
	10 a 10^2	tectonic plates
	10 a 10^2	Exploitation of water on a large scale
	10^{-7} a 10^{-6}	earthquakes
10 a 10^2	10 a 10^2	Exploitation of oil and gas
10^0 a 10	10 a 10^2	Extracting solids
10^{-1} a 10^0	10 a 10^2	Charging the surface, consolidation, hidrocompactation
10^{-1} a 10^0	10^{-7} a 10^{-6}	Densification by vibration
10^{-2} a 10^{-1}	10^{-1}	Compression

Table 1. The soil subsidence according area, time, and origin, Scott (1979).

2. Techniques for measuring subsidence of the soil

Several independent methods can be found in the literature for measuring the seismic subsidence, like the gravimetric and magnetic, Laser Scan, aerial photographs, GNSS (Global Navigation Satellite Systems), which require integration with geological information, logs of wells, hydrological maps, etc. to allow validation data and isolation of the causes of subsidence (Thomas et al. 2004).

The gravimetric method can be used to measure displacements of the water body, subsurface erosion and accommodation (Blackely, 1996; Junior Tavares, 2009; Junior Tavares, 2008; Zidarov, 1990), and It can be used in cities and rural areas at various scales (1:100, 1:500, 1:10000). The gravimetric method not depending on the purchase of images to generate contour maps showed and a reduced requiring teams with two digital gravimeters.

In urban areas the technique for control GNSS altimetry measurement of soil subsidence requires simultaneous operation of dual frequency receivers same specs screening and calibration of antennas; Either it is necessary continuous measurement periods, staff costs, etc.., (Leick, 1995; Seeber , 2003; Romão et al. 2003; Monico, 2007).

The GNSS signal interference could be caused by buildings, vehicles vibrations, and protection of landmarks occupied by receivers hinder systematic measurement campaigns (Blachut et al., 1979).

Altimetric control points need to be outside the area of deformation to analyze the stability of the land and appropriate measurement techniques (Miranda, 2007; Soto, 2006; Burity and Seixas, 2005; Granemann, 2005; Chen and Chrzanowski, 1990; Chrzanowski et al. 1985), further defining the geodetic reference system (Sato et al., 2003, Sneed et al. 2002; Sneed et al. 2003; Dalazoana, 2005, Freitas et al., 1999; Medeiros, 1999).

Moreover altimetry obtained by the GNSS can be compared to data obtained with the above mentioned techniques.

2.1. The PSInSAR technique

In the context of interferometric techniques to measure subsidence is important to emphasize that the technique PSInSAR represents a paradigm for developers academics studying the accuracy of DInSAR to measure subsidence and also create new algorithms capable of detecting PS.

Researchers like Chang and Rizos (2005), Elias et al. (2009), Zhou (2009), Froguer et al. (2007) have developed their own mathematical tools and methodologies to detect PS from classical DInSAR repository, obtaining good results in the measurement of subsidence on cost/benefit and accuracy of the order of cm/year to mm/year (Duy 2009; Thomas et al. 2004).

Mora et al. (2007) used in the town of Cardona, in the central region of Catalonia, Spain, with DInSAR, fewer images and precision compatible technique PSInSAR.

Henriques et. al. (2011) Describe a study of land subsidence in Lisbon Area with Validation Of PsinSAR Results.

The technique PSInSAR was created and patented in 1999 by a group of electronics engineers from Polytechnic University of Milan (POLIMI), Italy, with several applications, among which the measurement of soil subsidence (Ferretti, et al. 2001). The group owns the property POLIMI algorithm PSInSARTM technology spin-off company in Tele-Rivelamento Europe - TER since 2000 on five continents. Mapping subsidence of soil using the technique PSInSAR detecting vertical movements can achieve accuracy in the order of magnitude of cm / year or until mm / year (Ferreti et al. 2001).

2.2. Principles of the theory of subsidence measurement using DInSAR

The DInSAR Remote Sensing technique can be used in the acquisition altimetry and integrating interferometry SAR images (Shearer, 1998; Abidin et al. 2001; Colesanti et al. 2,005, Matthias, 2006, Matias et al. 2005; Ostir and Komac, 2007; Elias et al. 2,009; Chang, 2000; Ferreti et al. 2001; Lauknes, 2004; Fruneau et al. 2003).

Figure 1 shows the fundamental DInSAR geometry. The point is the acquisition of O_M reference O_S and the acquisition of repetition. The term B is the baseline interferometric with B_T component perpendicular and parallel B_P. The term R_M is the slant range in decision O_M, O_S and R_S in sight. The viewing angle θ is the sensor for one pixel in the soil; $d\theta$ is the difference between P_1 and P_2 sight. The sensor is ellipsoidal height h, and the difference in altitude between P_1 and P_2 is h_P. The angle α to the horizontal sensor θ_0 is at zero altitude.

There are several possible combinations of images for measuring subsidence in terms of baseline critical, requiring careful analysis to determine a correct combination to generate the interferogram and the degree of coherence between images. A baseline interferometric too small or too large, can disable the generation of the interferogram because this factor is based on the appropriate acquisition geometry, there is a critical baseline to consider. A coherent mix between takes O_M and O_S determines the phase difference pixel by pixel, there are fundamental knowledge and high spatial correlation ephemeris accurate sensors in O_M and O_S (Lauknes, 2004).

Differences in the geometry acquisition generate geometric decorrelation. Each image has a particular geometry acquisition and does not repeat exactly due to the differences in orbital coordinates (Lauknes, 2004). The difference phase information obtained from the sensor ASAR (in two different positions of the passage) is essential information to generate the interfero-

gram (Lillesand et al. 2004; Jansen, 2000; Mather, 1999, Cracknell and Hayes, 1991; Ferreti et al. 2,006; Farina et al. 2006). Assuming the phase and for a particular pixel, the acquisition identical O_M and O_S (Figure 1), the main value of the interferometric phase is expressed in Equation (1), where dR is the difference in slant range for a given pixel, and the length λ wave sensor (Sandwell and Price, 1998).

$$\Delta\varphi = -\frac{4\pi(R_M - R_S)}{\lambda} = -\frac{4\pi dR}{\lambda} \tag{1}$$

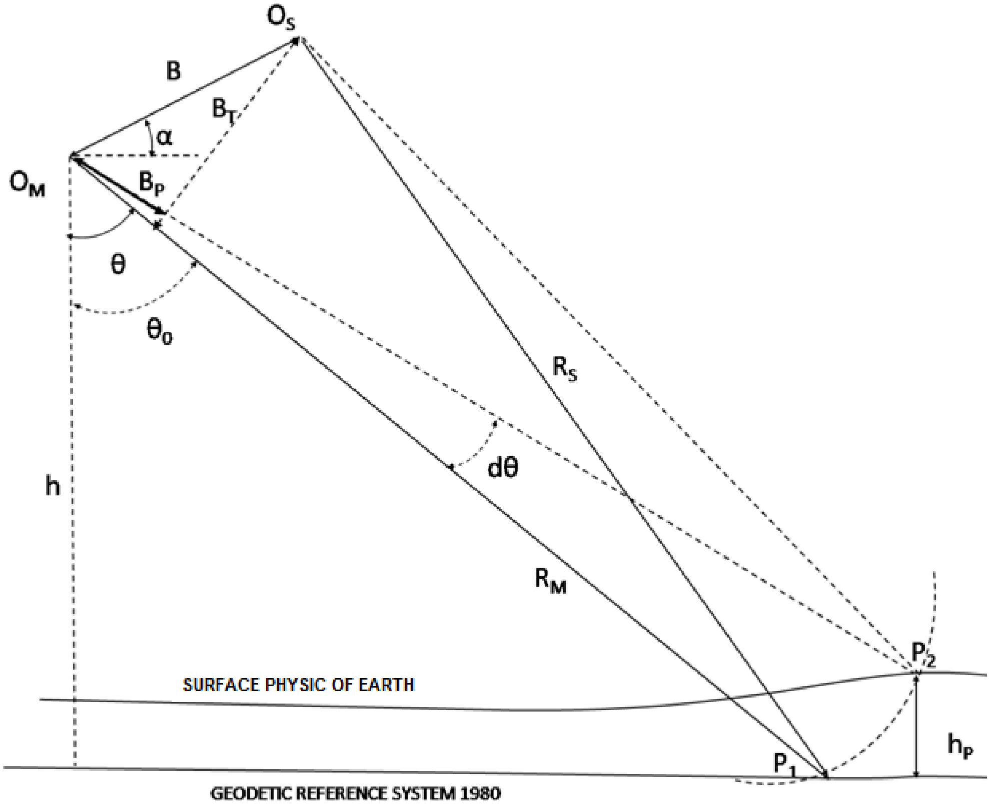

Figure 1. Basic Geometry DInSAR acquisition dual pass.

As the acquisition conditions between O_M and O_S , other terms that change the final value of the interferometric phase could be appear. The difference phase $\Delta\varphi$ pixel by pixel between P_1 and P_2 (see Figure 1) is expressed in Equation (2) where B_P is the perpendicular on the base B, λ the wavelength, the height difference dh between P_1 and P_2; $d\rho$ is ground deformation between acquisitions, and the term s represents the noise surrounding the

signal, atmospheric artifacts, radio broadcasting properties of targets, thermal noise of the sensor, among other sources (Massonet and Rabaute, 1993).

$$\Delta\varphi = \frac{4\pi B_p}{\lambda R.\tan\theta} dR + \frac{4\pi B_p}{\lambda R.\sin\theta} dh + \frac{4\pi}{\lambda} d\rho + s \qquad (2)$$

The subsidence in the ground is tied to the Geometry DInSAR acquisition geometry, and when the contribution of the first two terms of Equation (2) are removed (and assuming the fourth term negligible in the case of high temporal and spatial correlation between the images), the phase depends only on the deformation of the soil. The cyclic property of the interferometric phase (0 to 2π) of each pixel requires it be removed to analyze the subsidence of soil, within the process called unfolding phase in calculating the absolute phase of pixels (Matias, 2006).

3. Some studies and applications of techniques DInSAR PSInSAR in Brazil

In this section, some studies of Brazilian experience with PSInSAR in public domain applied to real cases will be shown.

In Paradella et al. (2005) present the use of SAR data and prospects for geological mapping applications and with the imminence of radar operation multipolarized airborne, polarimetric and interferometric SIVAM-SIPAM and prospects for the ALOS / PALSAR and RADARSAT-2.

Some multidisciplinary Brazilian works using SAR images application can be found in:. A) Mura (2005) and Gomes et al., (2005) have a forest application; B) deforestation and fire are presented in Bufalo and Valeriano (2005); C) Geomorphology in France et al., (2005) and Elmiro et al. (2005) within the InSAR technique. Another application involving radar images is shown in D) Picco et al. (2007) which addresses the development of filter for SAR images, in Geomorphology (Dutra et al. 2005), and altimetry (Oliveira et al., 2009). The following sums up what has been developed in these articles.

In the work developed by Mura (2005) have been two methods for improving the consistency with projection vectors to represent the backscatter signal of the targets. It is used in this article polarimetric and interferometric

data of banda P, acquired in the Tapajós National Forest in 2000. It is observed that due to the penetration of the microwave signal in the P band has not only the acquisition of interferometric phase practically at ground level, but also parameters that describe the structure of the forest.

Gomes et al. (2005) show different processing digital images made to ratings in JERS-1/SAR SPRING environment and evaluate these results from the Kappa coefficient, calculated from the confusion matrices. We also analyzed the results using filters before the process of segmentation and classification of these images.

Buffalo and Valeriano (2005) show in their work that can obtain verification of areas burned detectable from the data mosaic of JERS-1 (SAR) of GRFM. They check that from the refinement of the methodology has a complement of PRODES Digital, developed by INPE.

France et al., 2005 show in his work an assessment of the loss of information in the mapping of fluvial forms due to the degradation of spatial resolution in an image RADARSAT,C band. The area chosen for the job is set along the lower Amazon, the southern city of Obidos, in the state of Pará

Elmiro et al. (2005) developed his work on digital elevation models (DEM) generated from SAR interferometry obtained in the Amazon region for a correction method based on MDE surfaces errors determined by triangulation with linear interpolation. The three-dimensional models in use were obtained from a system of SAR polarimetry complete banda P and HH polarization in the X band AeroSensing RadarSysteme GmbH held that flight in the Tapajós National Forest and vicinity.

Picco et al. (2007) present a brief review of a multiplicative model for SAR images univariate discusses new filters MAP, describe the experience of Monte Carlo and criteria to evaluate the performance of the filters presented.

Oliveira et al. (2009) show the initial results achieved in the generation and evaluation of a MDE altimetric TerraSAR-X generated from a stereo pair of images acquired in SpotLight mode (SL).

Guerra, Cecarelli and Lomonaco (2011) studied the viability of the DInsar and PSInSAR with TerraSAR X to monitoring the surface around the Salto Pilão-SC hydroelectric.

Finally, Paradella et al. (2012) show a review of the main SAR and INSAR concepts and application perspectives of these technologies in Brazil.

3.1. Area of interest

The neighborhood of Boa Viagem, Recife, Pernambuco, Brazil (Figure 2) is located south of Pernambuco Shear Zone, the main geological structure and structural control that divides the basin sedimentary Paraíba and Pernambuco Basin. This neighborhood has overexploitation of aquifers sectors and to the north, a large wetland vegetation - Mangrove Park. Boa Viagem has variable range of sand with palm trees, liquid surfaces on the edge of the sea and mangroves surfaces whose dielectric parameters and polarimetric signatures generate temporal decorrelation and should be excluded from processing images. This area is geologically sedimentary and overpumping of wells reduces the pressure exerted by water generating support redistribution of grains and soil subsidence, which can reach a few centimeters per year and extending several kilometers (Cabral et al., 2006).

The site http://www.abequa.org.br/trabalhos/gerenciamento_363.pdf shows some results about aquifer monitoring of the study area.

(a) (b)

Figure 2. Neighborhood of Boa Viagem, Recife, Brasil. (a) Location of the area. Source: Santos (2005) . (b) Photo of the urban beach of Boa Viagem. Fonte: Teresa Maia – www.pernambuco.com

The temporal decorrelation depends on the stability of the back-scattering of targets between the acquisition dates of the images.

Boa Viagem in the buildings of concrete and metal fixed targets be appropriate to have good correlation (good retro-reflectors in C band. Decorrela-

tion generate targets susceptible to deletion or change of position, orientation and shape, as trees, fences, vehicles (heavy traffic in Recife), mounts regular temporary stage on the beach typical of Boa Viagem, paving roads, and any other built structure removed or not present at all radar images. Other targets can generate decorrelation as construction of new buildings within very dynamic removal of houses and old buildings replaced by towers of 30 floors in Recife, installation of guard rails, walkways, electronic speed bumps, bridges, viaducts, suspended pipelines, networks electricity transmission, etc.. The local knowledge of these urban characteristics is important in understanding the temporal decorrelation during the image processing and analysis and appropriate choice of spectral filters or computer algorithms to be applied.

In the images ASAR (Advanced Synthetic Aperture Radar) of ENVISAT (C band wavelength of 3.8 cm to 7.5 cm - frequency range from 4.0 to 8.0 GHz) modes swath IS_2 and IS_3 in orbits descending and ascending cover such additional points on the ground in the neighborhood of Boa Viagem, as the pattern and road corridors between buildings, which are referred to the most appropriate measurement of soil subsidence. The combination of the mentioned orbits seeks to circumvent effects of ASAR images on flat terrain with many buildings generating vertical radar shadows caused by east-west line north-south buildings very close together points covering the soil capable of GNSS monitoring, complicating the comparison of GNSS and altimetry altimetry with DInSAR technique.

4. Conclusion

The overexploitation of groundwater with the use of wells for situations requiring a demand exceeding the availability of the subterranean reservoir, the well tends to lead to exhaustion altering the structure of the soil and enhancing the lowering of the soil due to compression underlying porous layers, a phenomenon known as soil subsidence.

This work showed a review of work on the DInSAR technique with potential application to interferometry to Boa Viagem, Recife, Brazil. From this technique it is possible to verify the changes on the ground with overexploitation. As seen DInSAR technique is independent of other techniques for measuring subsidence whereas the ASAR sensor system is not located in the soil-building.

Other types of phenomena (seismicity, underground works, etc.)., Besides the overexploitation of aquifers, subsidence can cause soil and occur in the same time zone and area of overexploitation of aquifers, making the separation of causes of soil subsidence.

The consideration of the geological characteristics of Boa Viagem and the current land use and trends are essential for the processing of ASAR images using the DInSAR technique, a technique that is adequate to the problem of measuring soil subsidence in Recife and depending on the his greatest scientific dissemination regarding technical PSInSAR.

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